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Concentric and eccentric isokinetic hamstring injury risk among 582 professional elite soccer players: a 10-years retrospective cohort study

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ABSTRACT

Background/Aim Different authors have tried to correlate the peak isokinetic torque values with the incidence of soccer match injuries. However, due to the wide variety of assessment testing protocols, such an inference becomes difficult. This study aimed to verify the capacity of an isokinetic test to establish injury risk reference values for hamstring strain injuries.

Methods A retrospective cohort study based on isokinetic data and clinical records from the last 10 years was conducted in 582 Brazilian elite-professional soccer players, who were subjected to the same isokinetic test protocol, machine, and tester. A Multivariate Logistic Regression Analysis for Complex Data Sampling was used to generate injury risk statistical indexes.

Results Multivariate regression analysis of both legs provided important data to identify the cut-off values of Concentric Peak Torque (181.82 Newton/*metres), Concentric Work (236.23 watts) and Concentric Power (130.11 joules).

Conclusions The injury risk indexes indicate that an increase of just one Newton unit in CPT (Concentric Peak Torque) and CJ (Concentric Power) above those cut-off values, can reduce the risk of future injuries by 2% and 2.7%, respectively.

INTRODUCTION

The most common sport injuries in soccer is muscle strains. In the 2014 Soccer World Cup, muscle strains accounted for 24% of the all injuries reported, with two-thirds of the total injuries located in the lower limb.¹ Furthermore, hamstring injuries are among the most common non-contact injuries in sports involving running² and generate a long-term absence from soccer matches (average of 17 days).³ Hamstring injuries also have a high number of recurrences, ranging from 16 to 20%.⁴ However, biomechanic risk factors related to lower limb muscle injuries in professional soccer are still debated. Although the multivariate origin of sports injury,

Summary box

What are the new findings

- ▶ A long (10 years) analysis of muscle injuries in professional-elite soccer players.
- ▶ A structured, standardized isokinetic protocol by the same physical therapist including concentric and eccentric muscle contractions.
- ▶ An advanced multivariate regression analysis covering diverse variables that could affect injury risk.
- ▶ Cutoff values of Concentric Peak Torque, Work and Power that could guide clinical practice decision making.

biomechanical factors, such as muscle strength, has been used to investigate its relationship with injuries event in matches or training.^{1 2 5 6}

Isokinetic peak torque has been used to measure athletic⁷ and clinical conditions⁸ and even as a diagnostic parameter.⁹ Although, the present literature does not present enough consensus to justify the use of the lower limb's bilateral torque asymmetry as a hamstring's injury risk predictor.^{3 10-14}

Different authors have investigated the association between isokinetic peak torque values with the incidence of injuries in soccer since bilateral asymmetry and eccentric muscle torque weakness have been related to lower limb muscle injuries.^{2 4 15-17} As muscle strain is the most common injury in soccer a weak muscle would be subjected to more risk of failure and injury.¹⁸

However, there is a wide variety of assessment testing protocols previously used, which includes different equipment model, preparation procedures, population studied and duration of the follow-up period. Since such variety of testing protocols can influence the test's results, there is still a demand for studies with longer follow-up periods, with a homogeneous population and evaluated by the same testing protocol. In addition, other



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parameters, such as power and eccentric peak torque, were not properly considered in previous studies and may help to understand the relationship between these variables and future lower limb injuries in professional elite soccer players.^{12 14 19}

This study aims to: (i) verify if isokinetic test variables are associated with future hamstring injuries in professional elite soccer players and (ii) establish injury risk reference values for these variables. We hypothesise that isokinetic values of hamstrings may be used as reference values for injury risk of these muscles in professional elite soccer players.

METHODS

Design

This is a retrospective cohort study based on isokinetic data and clinical records of hamstring injuries in Brazilian elite-professional soccer players from 2009 to 2019. The study was carried out according to the Declaration of Helsinki, and a protocol was fully approved by the University Human Research Ethics Committee with number #3652668. This study followed the STROBE Statement recommendations.

Participants

Elite professional soccer players who had been playing for at least 5 years on first and second Brazilian divisions and training regularly one to two sessions per day, six times per week participated in this study. Demographic information is displayed in table 1 in the results section.

In order to be included in this study, players had to be able to fully participate in team training sessions and match play at the time of the analysis. Players who had a third-degree hamstrings or quadriceps muscular injury in the past 3 months, a knee surgery in the past 12 months, or currently in treatment from other muscular injury or illness were excluded from our sample.

The purpose, experimental procedures, possible risks and benefits of the study were explained to the athletes, who provided a written informed consent form to confirm participation in the study. For players under the age of 18, their parents or legal guardians were informed of

the risks and signed an informed consent before investigation enrolment.

Procedures

Participants were requested to eat according to their team's nutritionist prescribed diet 48 hours preceding the assessment and then refrain from eating and drinking substances other than water 1 hour before the assessment. All tests were carried out in January, few weeks before Brazil's Regional Championship season starts; and players were instructed to refrain from strenuous activities 48 hours before testing.

For data collection were used: an isokinetic dynamometer (Cybex-CSMI, model HumacNorm 2009, Stoughton, Massachusetts, USA) with signal acquisition rate of 500 Hz. In order to improve players' test understanding, were used a modified 10-points Borg scale (BORG) for perceived exertion⁷ where zero was no strength effort and 10 the maximum strength effort possible; and a visual analogue pain scale; where zero was 'no pain' and 10 was 'worst pain imaginable' (VAS).⁸ For data storage and processing was used a Macbook Pro Notebook (Cupertino, California, USA) equipped with Microsoft Office software package for Mac (version 2011, Redmond, Washington, USA) and Statistical Package for Social Sciences (SPSS) from IBM (Armonk, NY, USA).

Upon arrival, the players were provided with appropriate explanation and demonstration of all procedures. The players informed the most frequently field position in the past year's games. Only athletes who played in their usual positions were included in the sample. Positional groupings were goalkeepers (G), defenders (D), wing-backs or 'external defenders' (W), midfielders (M) and forwards (F). Dominant leg was defined as their preferred kicking leg for a penalty kick. Anthropometric information (weight in kilograms, height in centimetres) was recorded by the same team nutritionist before the isokinetic test.

All subjects were submitted to a testing protocol following the guidelines of APTA—American Physical Therapy Association^{9 10 20 21} and soccer-specific studies using

Table 1 Demographic data

| | Mean | SD | Min–Max |
|--------------------------|--------------|-----------------------|--------------------------|
| Age (years) | 24,4 | ±4,5 | 17–37 |
| Weight (Kg) | 77,8 | ±7,8 | 59–108 |
| Height (cm) | 180 | ±6,8 | 159–200 |
| BMI (kg/m ²) | 23,8 | ±1,5 | 19,6–2899 |
| Injuries | Total | Dominant Side | Non-Dominant Side |
| Athletes | 583 | 17 | 19 |
| Injuries | 36 (6.19%) | 17 (2.92%) | 19 (3.26%) |
| Peak Torque (PT) | | Concentric | Eccentric |
| Dominant Leg | | 18 325 N*m/BW (±3286) | 21 938 N*m/BW (±4592) |
| Non-Dominant Leg | | 17 949 N*m/BW (±3237) | 21 308 N*m/BW (±4390) |

isokinetic machines.^{11–13} The same physiotherapist, with 10 years of experience, performed all isokinetic tests. All isokinetic tests were performed bilaterally.

Concentric test

Participants were positioned on the seat of the isokinetic dynamometer and executed 10 repetitions of concentric knee flexion and extension, both with velocity of 90° per second and range of motions of 100° for warming up purposes (Borg up to 5, VAS up to 1, or test interrupted); followed by a rest period of 120 s. The warm-up on the isokinetic machine was chosen to improve specificity and familiarisation with the following test.¹⁰ The athlete then performed five concentric repetitions of knee flexion and extension at 60° per second for familiarisation with the exercise velocity, followed by another rest period of 120 s. Then, they performed three concentric repetitions of knee flexion and extension (velocity: 60° per second and range of motion: 100°) with maximum effort (Borg 10), receiving continuously, the standardised verbal encouragement: 'Faster'. The presence of pain equal or superior to 05 on VAS interrupted the test, cancelling it and excluding the subject from sample. The repetition with higher peak torque value of all three repetitions was used for statistical analysis.

Eccentric test

The eccentric test was performed at 60° per second and range of motion of 100°. The subject executed five repetitions of warm-up and familiarisation followed by three repetitions at maximum effort (Borg 10), receiving constantly the standardised verbal encouragement: 'Hold it.' The presence of pain equal or superior to 05 on VAS interrupted the test, cancelling it and excluding the subject from sample. Between each set of exercises, subjects had 120 s to rest. Between each limb's test, participants had 120 s to rest.

Data analysis

Concentric Peak Torque (CPT) and Eccentric Peak Torque (EPT) of knee extensors and flexors were extracted from the isokinetic machine by its manufacturer's dedicated software (HumacNorm 2009, CSMi Inc, Boston, US) and normalised by each subject's body weight. Concentric Work (W) in Watts, and Concentric Power (CJ) in Joules, were also extracted from all test and normalised by body weight.

Injury records were extracted from each player medical records, with written consent from their team chief physician and sport institution. Only first and second-degree hamstring injuries were included in this study.

The Descriptive Analysis of the data was composed by simple and relative frequency of the variables: Concentric Peak Torque (CPT), Eccentric Peak Torque (EPT), Concentric Work (CW), Concentric Power (CJ), Age, Weight, Dominance, Field Playing Position (Position), Injured

Leg (Injured), Time in days between Isokinetic Testing and Hamstring Injury (Time).

It was also used a Multivariate Logistic Regression Analysis for Complex Data Sampling. The Regression Analysis was made using SPSS software version 23 (2015), with Complex Samples Module, to assess associations and OR, between hamstring injuries and isokinetic variables.

Patient and public involvement

There was no involvement from patients or members of the public in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

Anthropometric and epidemiological data of all 582 participants concerning the last 10 years of injury events are shown in [table 1](#). On average, our sample consisted of right-footed athletes (72%) with 24.4±4.5 years old, 77.8±7.8 kg, 180.5±6.8 cm, and Body Mass Index (BMI) of 23.8±1.5 kg/m². Our sample reported 37 hamstring injuries in the last 10 years that satisfied our inclusion criteria; 17 on the dominant side, and 19 on the non-dominant side. [Table 1](#) also shows the sample means of CPT (128.25±32.86 Nm, 179.49±32.37 Nm), EPT (219.38±45.92 Nm, 213.08±43.90 Nm) of dominant and non-dominant knee flexor muscles normalised by body weight, respectively.

The Kolmogorov–Smirnov and Shapiro–Wilk normality tests were applied, and these variables showed normal distribution. For multivariate regression analysis, the cut-off points were analysed according to the limb in which the injury occurred (dominant, non-dominant). Additionally, were calculated: frequency estimation (absolute and relative) of the model's categorical variables; ROC curve and the area under the curve (AUC) with 95% CI (95% CI). Subsequently, sensitivity and specificity cross-tab tests were run for each cut-off point with statistical significance and calculated the values of Positive Likelihood Ratio (PLR), Positive Predictive Value (PPV), Negative Predictive Value (NPV) and Accuracy. All calculations considered a level of significance of 0.05; and are displayed in [tables 2–4](#).

When considered both legs (dominant and non-dominant) in multivariate regression analysis, it was found that a Concentric Peak Torque (CPT) lower than 170.83 N has a higher probability of general hamstring injuries in any of both legs (AUC 0.589; CI95% =0.548–0.629; sensitivity 77.78, specificity 39.01; *p*=0.0468). The accuracy found was 39.01%, with a PLR of 2.14, PPV of 62.03% and NPV of 77.78%. When considered only the non-dominant side, CPT showed statistical significance with a cut-off value of 181.82N for the prediction of hamstring injury risk (AUC 0.671; CI 95%=0.631–0.709; sensitivity 78.95, specificity 54.00; *p*=0.0021). The accuracy found was 54.0%, a PLR of 4.22, PPV 47.08% and NPV of 78.95%. Isokinetic concentric power (CJ) also showed statistical significance when considered only the non-dominant side, with a cut-off value of 130.11 joules (AUC 0.636; CI 95%=0.595–0.675; sensitivity 84.21, specificity 45.65;

Table 2 Injury risk indexes

| | Dominant side | Non-dominant side | |
|---------------------------|-----------------------|-----------------------|-----------------------|
| | CPT | CPT | CJ |
| Positive Group | 36 (6,19%) | 19 (3,26%) | |
| Negative Group | 546 (9381%) | 563 (9674%) | |
| AUC | 0,589 | 0,671 | 0,636 |
| SE† | 0,0447 | 0,0556 | 0,0518 |
| 95% IC‡ | 0,548 to 0,629 | 0,631 to 0,709 | 0,595 to 0,675 |
| Z Statistic | 1988 | 3,07 | 2618 |
| Level of significance (P) | 0,0468 | 0,0021 | 0,0089 |
| Youden index (J) | 0,1679 | 0,3294 | 0,2986 |
| Associated criteria | >17 083 | >18 182 | >13 011 |
| Sensibility | 7778 | 7895 | 8421 |
| Specificity | 3901 | 54 | 4565 |

†DeLong *et al*, 1988.

‡Binomial exact.

Table 3 Sensitivity and specificity of statistically significant variables

| Tests | Formula | Concentric Peak Torque (CPT) Results (IC95%) | | Concentric Power (CJ) Results (IC95%) | |
|---------------------------|---|--|------------------|---------------------------------------|------------------|
| | | | | | |
| Sensitivity | $\frac{a}{a+b}$ | 5.47% | 3.10% to 8.87% | 4.97% | 2.87% to 7.94% |
| Specificity | $\frac{d}{c+d}$ | 98.70% | 96.71% to 99.65% | 98.85% | 96.67% to 99.76% |
| Positive Likelihood Ratio | $\frac{\text{Sensitivity}}{1-\text{Specificity}}$ | 4.22 | 1.42 to 12.55 | 4.31 | 1.27 to 14.62 |
| Disease prevalence | $\frac{a+b}{a+b+c+d}$ | 0.96 | 0.93 to 0.99 | 0.96 | 0.93 to 0.99 |
| Positive Predictive Value | $\frac{a}{a+c}$ | 47.08% | 42.96% to 51.23% | 55.33% | 51.18% to 59.42% |
| Negative Predictive Value | $\frac{d}{b+d}$ | 78.95% | 55.75% to 91.78% | 84.21% | 61.10% to 94.77% |
| Accuracy | $\frac{a+d}{a+b+c+d}$ | 54.00% | 53.22% to 54.77% | 45.65% | 44.95% to 46.35% |

a (True Positive), b (False Positive), c (False Negative), d (True Negative).

IC 95%, 95% Interval of Confidence.

Table 4 Crude and adjusted analysis of statistically significant variables

| Statistically Significant Variables | Dominant Side Injury | | | | Non-Dominant Side Injury | | | |
|-------------------------------------|----------------------|------------|-------------------|--------------------|--------------------------|------------|-------------------|------------|
| | Crude Analysis | | Adjusted Analysis | | Crude Analysis | | Adjusted Analysis | |
| | OR | IC 95% | OR | IC 95% | OR | IC 95% | OR | IC 95% |
| CPT Dominant Side | 0,989 | 0,975–1004 | 0,980* | 0,961–0,999 | 1016* | 1001–1031 | 1005 | 0,985–1025 |
| CPT Non-Dominant Side | 1002 | 0,987–1017 | 1016 | 0,995–1037 | 1020* | 1005–1034 | 1016 | 0,997–1036 |
| CJ Dominant Side | 0,982 | 0,964–1001 | 0,973* | 0,949–0,998 | 1014 | 0,998–1030 | 1005 | 0,983–1027 |
| CJ Non-Dominant Side | 0,996 | 0,975–1017 | 1016 | 0,987–1045 | 1021* | 1000–1042 | 1017 | 0,991–1044 |

*p<0.05.

Absence of injury is the reference variable in multimodal regression analysis.

IC 95%,95% Interval of confidence; OR, Odds ration.

p=0.0089). The accuracy found was 45.65%, with PLR of 4.31, PPV of 55.33% e NPV 84.21%.

When considered only the dominant side, an association was found between concentric peak torque (CPT) on the dominant side and decreased risk of injury. The OR (OR =0.980; P=0.037) suggests a reduction by 2% of injury risk for each CPT unit (in Newtons) the athlete has above the cut-off value. There was also an association between isokinetic power (CJ) of dominant side and

reduced risk of injury. The OR (OR=0.973; p=0.037) suggests a reduction by 2.7% of injury risk for each CJ units in Joules the individual has above the cut-off value. No associations were found for the other independent variables.

DISCUSSION

The ability of an isokinetic test to detect risk factors for hamstring injuries in professional elite soccer players is

controversial in the current literature. Some studies analysed only concentric peak torque, omitting other variables provided by the test, such as eccentric peak torque, concentric power and work.^{11 13 14 19}

Multivariate regression analysis of both legs provided important data to identify the cut-off values of CPT (181.82 newtons), CW (236.23 watts) and CJ (130.11 joules). They can be used as reference parameters to reduce hamstring injury risk in professional elite soccer players, as values above those cut-offs suggest a protective strength level against injuries of the hamstrings. A previous study has defined average values of CPT (14 206 N for right side and 13 305 N for left side) but did not consider player's laterality. Besides, they did not analyse the values of CW and CJ.^{4 22 23}

The model showed higher sensitivity than specificity, identifying athletes who have some muscular weakness degree, but didn't necessarily suffer injuries in the following season. It also presented a higher value for Negative Predictive Value (77.78%) than for Positive Predictive Value (62.03%), which indicates that the model is more sensitive to detect athletes who have not suffered hamstring injuries during the season following the tests. Other studies with comparable aims did not find similar results.^{2 5 15 24–26} We believe that the main reason for this disagreement is based on the high variability of isokinetic testing protocols used and the absence of long follow-ups on those research.

With multivariate regression analysis, it was found an association between CPT of dominant side and injury risk reduction for individuals who did not have hamstring injuries. It was calculated that each increase in the unit of measurement of the peak torque by body weight (Nm/BW), generates a 2% decrease in injury risk chance. Similarly, it was found an association between CJ of dominant side and reduced risk of hamstring injury during multivariate analysis. It suggests that each increase in the concentric flexor power unit (Joules) of dominant side decreases the risk of injury by 2.7%. Previous studies have found weak to moderate association between hamstring peak torque and muscle injuries. But these studies did not considerate the relation between athletes' laterality and injury side; which makes comparisons biased.^{16 22}

These OR values provide important data regarding the intervention in the hamstring muscle bilateral imbalances and weakness by sports-health professionals. The increase of one Newton unit in flexor peak torque and flexor power, can reduce the risk of future injuries by 2% and 2.7%, respectively. This indicates that a 10% increase in peak torque can generate a 20% reduction in hamstring injury risk for the coming season. As for power of the flexors, the same 10% increase (in joules) may represent a 27% reduction in hamstring injury risk for the coming season. This is a point of great relevance in this study, as it can serve as a reference for protocols of rehabilitation and intervention of prevention programmes of muscular strengthening. These findings are in disagreement with a previous study, which found association only between injury rate and the eccentric contraction phase.^{4 16 18}

CONCLUSIONS

According to the findings in the present study, we consider the isokinetic evaluation a tool able to indicate soccer elite athletes who do not have an adequate muscular balance; and in this case, more prone to severe hamstring injuries. Peak concentric torque of knee flexors below the cut-off values of 181.82 newtons showed a statistically significant hamstring injury risk in professional-elite level soccer players. Similarly, 236.23 watts of muscular work and 130.11 joules of power are cut-off values for hamstrings injury risk.

OR values were found, which provide valuable information for referencing rehabilitation protocols of preventive intervention. The increase of one Newton unit in flexor peak torque and flexor power, can reduce the risk of future injuries by 2% and 2.7%, respectively. This indicates that a 10% increase in peak torque can generate a 20% reduction in hamstring injury risk for the coming season. As for power of the flexors, the same 10% increase (in joules) may represent a 27% reduction in hamstring injury risk for the coming season.

The present study identified an important risk factor and reference cut-off values for the main injury of professional soccer player, which through isokinetic evaluation, brings valuable information for sports managers, coaches, physical trainers, doctors and sports physiotherapists in search of better methods of preventing muscular injuries.

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REFERENCES

- 1 Al Attar WSA, Soomro N, Sinclair PJ, *et al*. Effect of injury prevention programs that include the nordic hamstring exercise on hamstring injury rates in soccer players: a systematic review and meta-analysis. *Sports Med* 2017;47:907–16.
- 2 Dauty M, Menu P, Fouasson-Chailloux A, *et al*. Prediction of hamstring injury in professional soccer players by isokinetic measurements. *Muscles Ligaments Tendons J* 2016;6:116–23.
- 3 Junge A, Dvořák J. Soccer injuries during the 2014 FIFA World Cup. *Br J Sports Med* 2015;49:599–602.
- 4 Fousekis K, Tsepis E, Poulmedis P, *et al*. Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. *Br J Sports Med* 2011;45:709–14.
- 5 Zvijac JE, Toriscelli TA, Merrick S, *et al*. Isokinetic concentric quadriceps and hamstring strength variables from the NFL scouting combine are not predictive of hamstring injury in first-year professional soccer players. *Am J Sports Med* 2013;41:1511–18.
- 6 Bourne MN, Timmins RG, Opar DA, *et al*. An evidence-based framework for strengthening exercises to prevent hamstring injury. *Sports Med* 2018;48:251–67.
- 7 Pincivero DM, Coelho AJ, Campy RM. Gender differences in perceived exertion during fatiguing knee extensions. *Med Sci Sports Exerc* 2004;36:109–17.
- 8 Robertson RJ, Goss FL, Metz KF. Perception of physical exertion during dynamic exercise: a tribute to Professor Gunnar A. V. Borg. *Percept Mot Skills* 1998;86:183–91.
- 9 Kannus P. Isokinetic evaluation of muscular performance: Implications for muscle testing and rehabilitation. *Int J Sports Med* 1994;15:S11–18.
- 10 Osternig LR. Isokinetic dynamometry: implications for muscle testing and rehabilitation. *Exerc Sport Sci Rev* 1986;14:45–80.
- 11 Houweling T, Head A, Hamzeh M. Validity of isokinetic testing for previous hamstring injury detection in soccer players. *Isokinet Exerc Sci* 2009;17:213–20.
- 12 Manou V, Arseniou P, Gerodimos V, *et al*. Test-retest reliability of an isokinetic muscle endurance test. *Isokinet Exerc Sci* 2002;10:177–81.
- 13 Amaral G, Marinho H, Ocarino J, *et al*. Muscular performance characterization in athletes: a new perspective on isokinetic variables. *Braz J Phys Ther* 2014;0.
- 14 Paul DJ, Nassis GP. Testing strength and power in soccer players: the application of conventional and traditional methods of assessment. *J Strength Cond Res* 2015;29:1748–58.
- 15 Lee JWY, Mok K-M, Chan HCK, *et al*. Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in soccer: a prospective study of 146 professional players. *J Sci Med Sport* 2018;21:789–93.
- 16 van Dyk N, Bahr R, Whiteley R, *et al*. Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injuries: a 4-year cohort study. *Am J Sports Med* 2016;44:1789–95.
- 17 Silva JRLC, Detanico D, Pupo JD, *et al*. Bilateral asymmetry of knee and ankle isokinetic torque in soccer players u20 category. *Revista Brasileira De Cineantropometria Desempenho Humano* 2015;17:195–204.
- 18 Häggglund M, Waldén M, Magnusson H, *et al*. Injuries affect team performance negatively in professional soccer: an 11-year follow-up of the UEFA champions league injury study. *Br J Sports Med* 2013;47:738–42.
- 19 Weber FS, Silva BGCD, Radaelli R, *et al*. Avaliação isocinética em jogadores de futebol profissional e comparação do desempenho entre as diferentes posições ocupadas no campo. *Rev Bras Med Esporte* 2010;16:264–8.
- 20 Logerstedt DS, Snyder-Mackler L, Ritter RC, *et al*. Orthopedic section of the American physical therapy association. Knee pain and mobility impairments: meniscal and articular cartilage lesions. *J Orthop Sports Phys Ther* 2010;40:A1–A35.
- 21 Ahtiainen JP, Pakarinen A, Alen M, *et al*. Short vs. long rest period between the sets in hypertrophic resistance training: influence on muscle strength, size, and hormonal adaptations in trained men. *J Strength Cond Res* 2005;19:572–82.
- 22 Fousekis K, Tsepis E, Vagenas G. Multivariate isokinetic strength asymmetries of the knee and ankle in professional soccer players. *J Sports Med Phys Fitness* 2010;50:465–74.
- 23 Fousekis K, Tsepis E, Vagenas G. Lower limb strength in professional soccer players: profile, asymmetry, and training age. *J Sports Sci Med* 2010;9:364–73.
- 24 Dauty M, Menu P, Fouasson-Chailloux A. Hamstring muscle injury prediction by isokinetic ratios depends on the method used. *Clin J Sport Med* 2020;30:40–5.
- 25 Orchard J, Marsden J, Lord S, *et al*. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian soccerers. *Am J Sports Med* 1997;25:81–5.
- 26 Bennell K, Wajswelner H, Lew P, *et al*. Isokinetic strength testing does not predict hamstring injury in Australian rules soccerers. *Br J Sports Med* 1998;32:309–14.